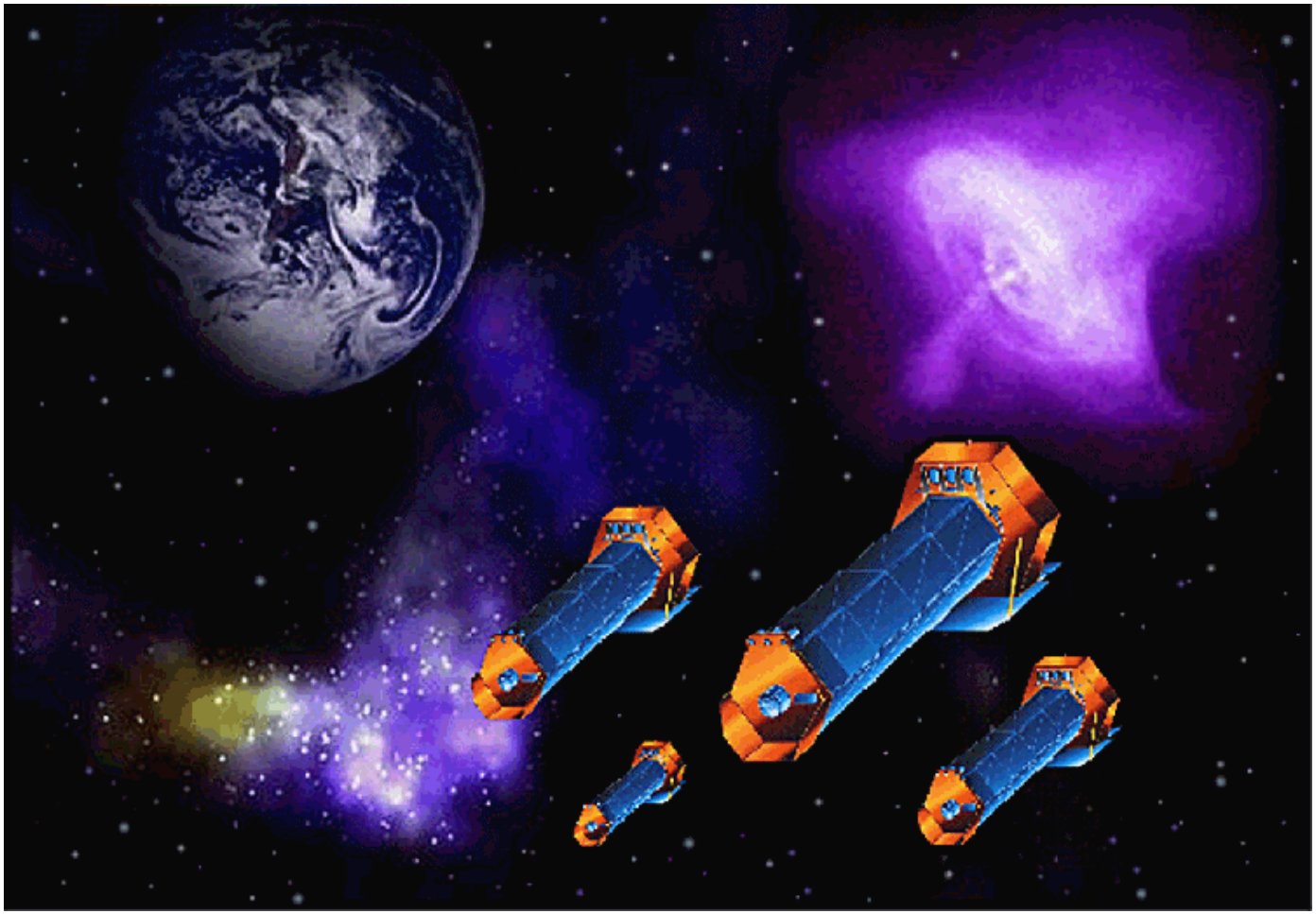
Constellation X-ray Mission



Jean Grady

Goddard Space Flight Center

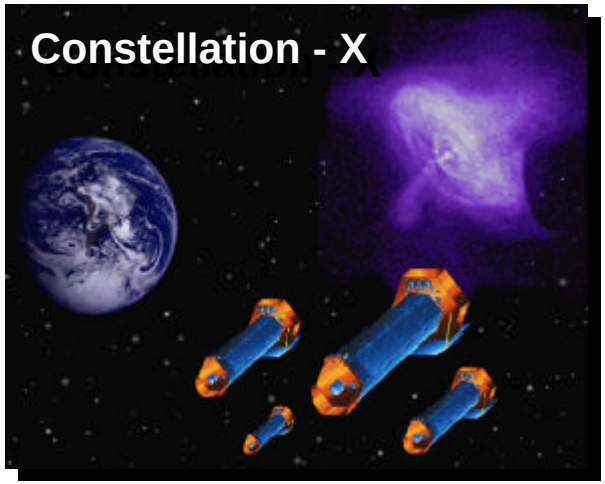
http://constellation.gsfc.nasa.gov

Highlights from the Past Year

- Refined definition of GSFC/SAO Reference Mission Configuration of four spacecraft and released description document
- Continued definition of top level mission requirements and flow down
- Began investigation of packaging option which utilizes fixed optical bench for potential mass and cost savings
- Fabricated 0.5 meter shell optic weighing 1 kg from new nickel alloy
- Demonstrated segmented optics components consistent with factor of three improvement in system resolution
- Achieved 2 eV resolution at 1.5 keV with single pixel X-ray calorimeters
- Improved CdZnTe detector energy resolution and threshold
- Demonstrated proof-of-concept for Resistive Gate CCD

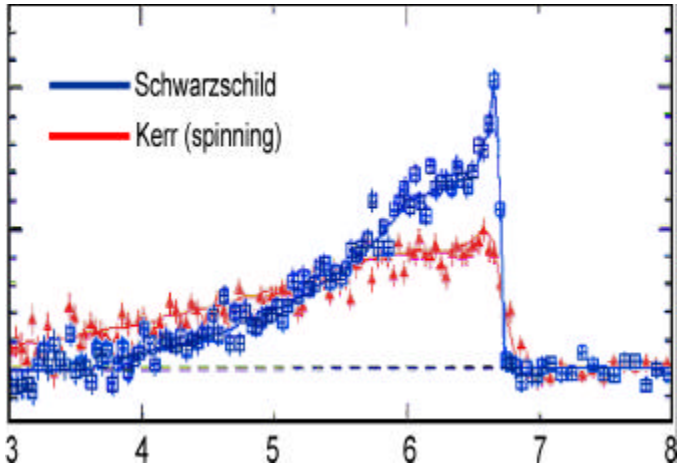
The Constellation X-ray Mission

Constellation-X is X-ray astronomy's equivalent of the Keck telescope

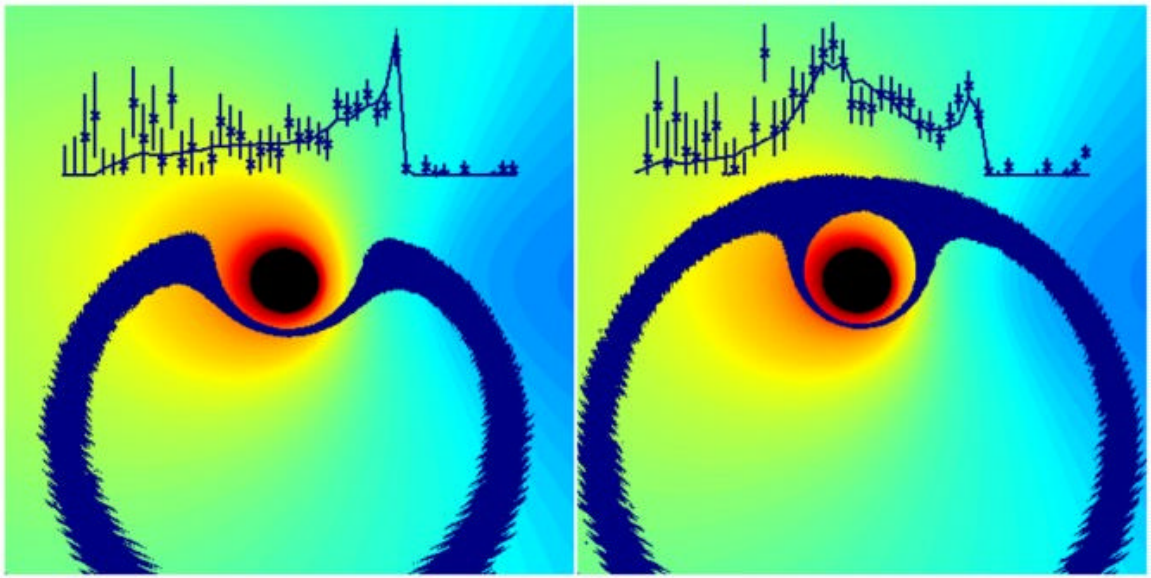


- **Collecting area: 30,000 cm² at 1 keV**
  100 times Chandra and XMM for high resolution spectroscopy
- **Spectral resolving power: 3,000 at 6.4 keV**
  25 times Chandra grating
- **Band Pass: 0.25 to 40 keV**
  100 times more sensitive than Rossi XTE at 40 keV

Probing Black Holes

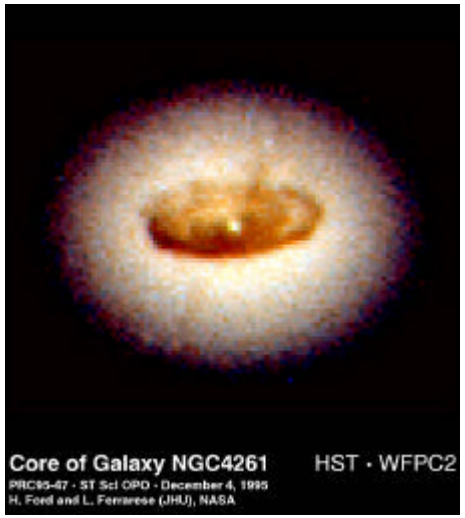


- **Constellation-X will probe close to the event horizon with 100 times better sensitivity than before**
  - Observe iron profile from close to the event horizon where strong gravity effects of General Relativity are seen
  - Investigate evolution of black hole properties by determining spin and mass over a wide range of luminosity and redshift

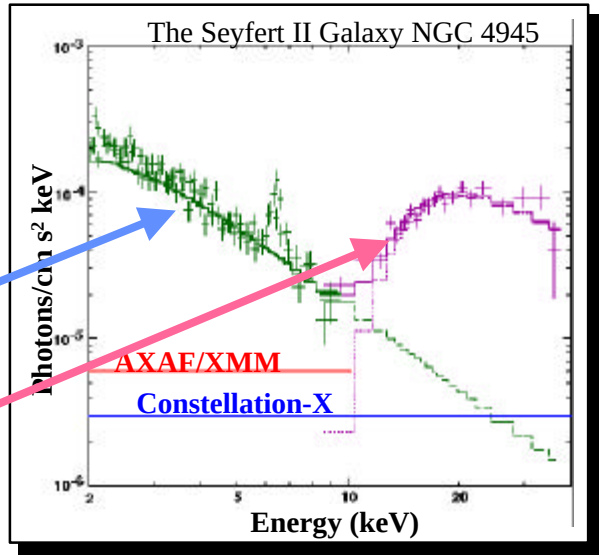


Simulated images of the region close to the event horizon illustrate the wavefront of a flare erupting above material spiralling into the black hole. The two spectra (1000 seconds apart) show substantial distortions due to GR effects.

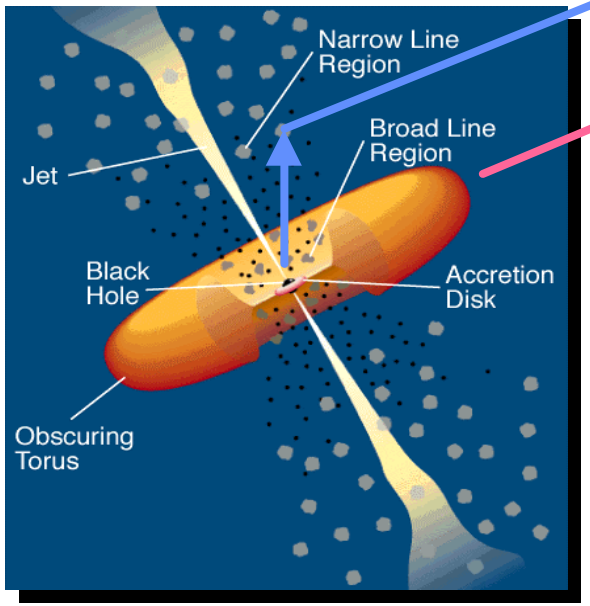
Hidden Black Holes



Many black holes may be hidden behind an inner torus or thick disk of material



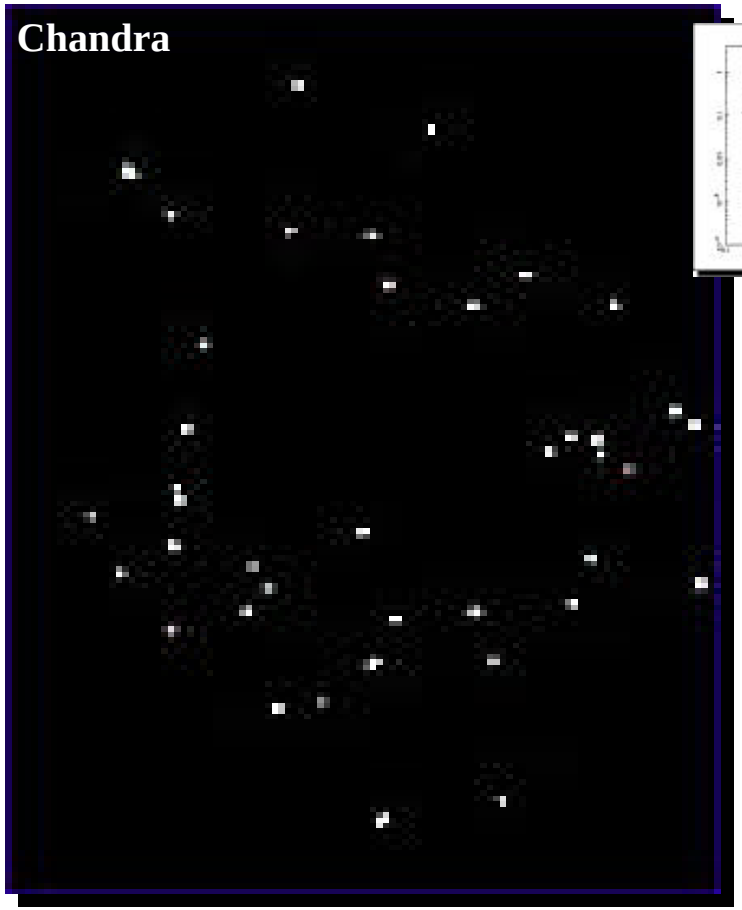
Only visible above 10 keV where current missions have poor sensitivity

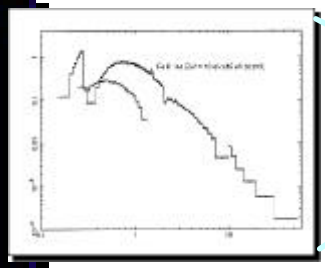


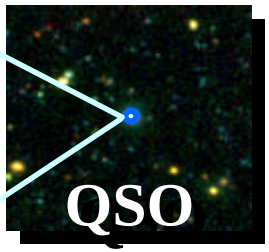
Constellation-X will use multi-layer coatings on focusing optics to increase sensitivity at 40 keV by >100 over Rossi XTE

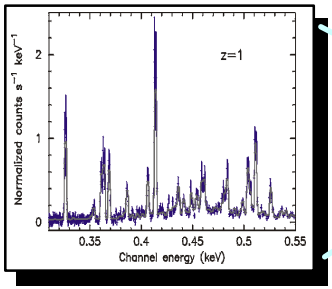
Chandra Finds Black Holes Are Everywhere!

Chandra deep field has revealed what may be some of the most distant objects ever observed









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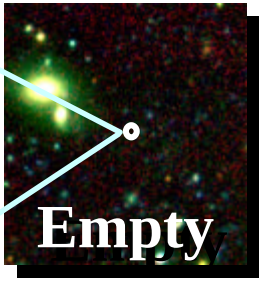
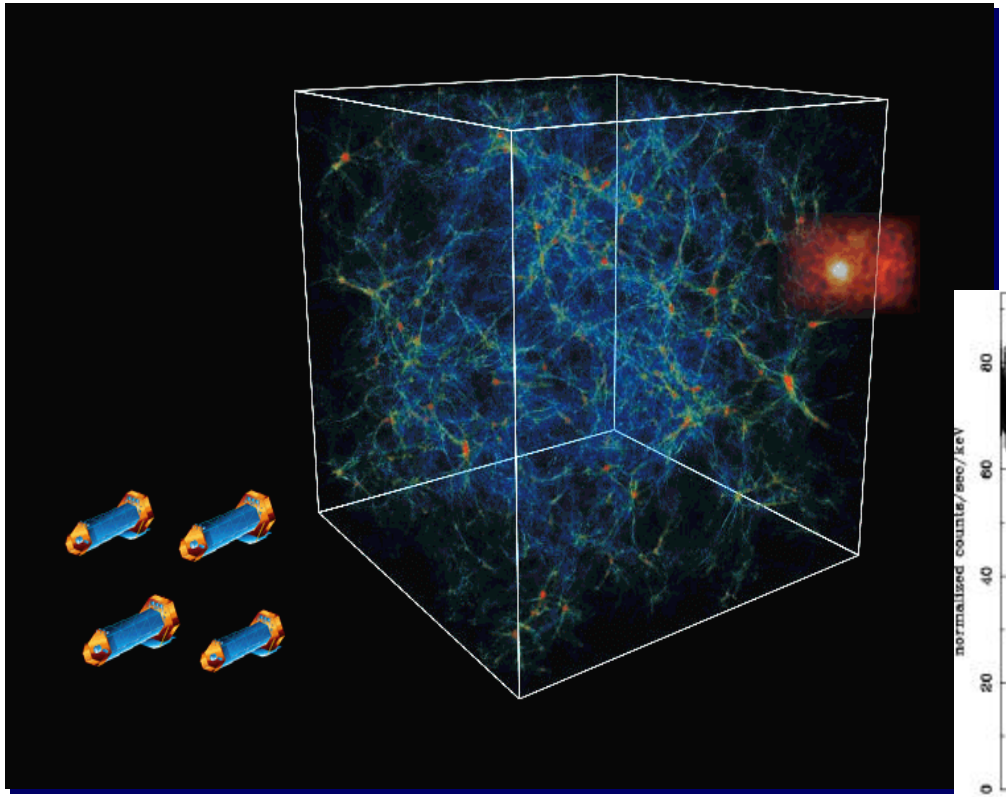


Constellation-X will obtain high resolution spectra of these faintest X-ray sources to determine redshift and source conditions

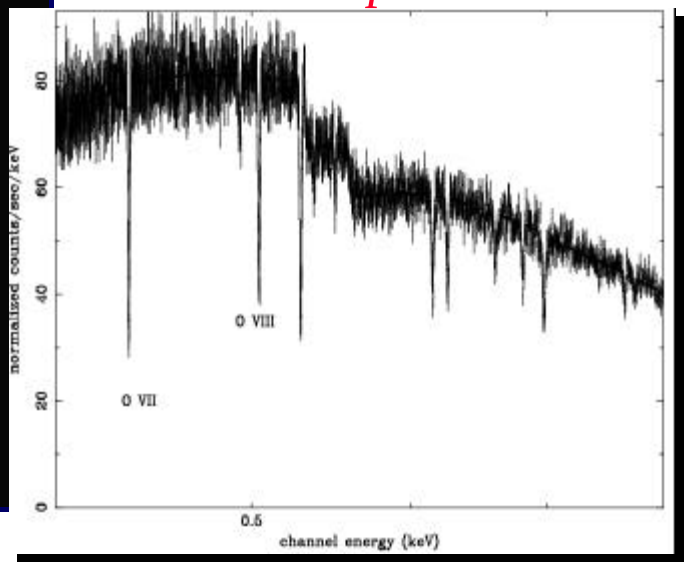
"X-raying" the Cosmic Web

- **Constellation-X will search for the missing baryons trapped in the Cosmic Web of dark matter**



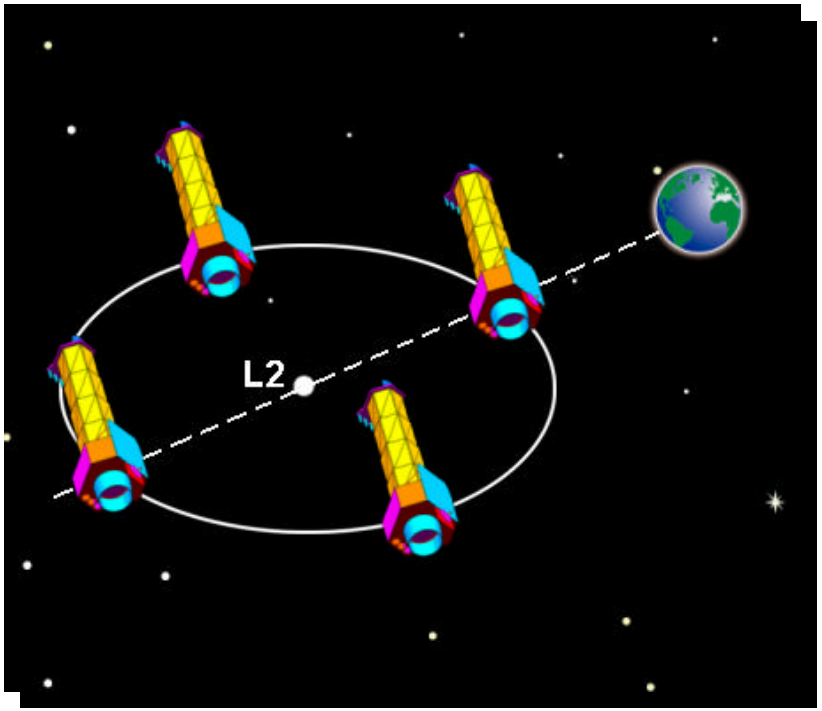
– Detect ionized gas in the hot Inter Galactic Medium via absorption lines in spectra of background quasars

Absorption



Constellation-X will probe up to 70% of the hot gas at low redshifts through OVII & VIII resonant absorption

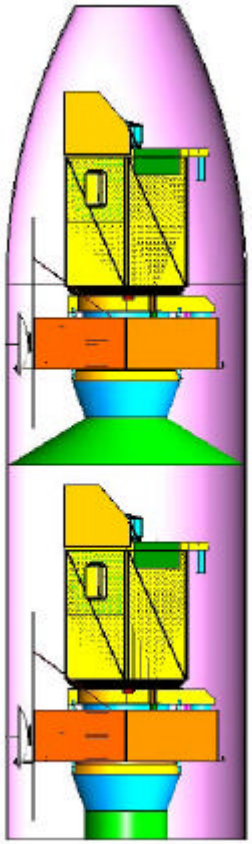
Constellation-X Mission Concept



- **A multiple satellite approach:**
  - A constellation of multiple identical satellites
  - Each satellite carries a portion of the total effective area
  - Design reduces risk from any unexpected failure
- **Deep space (L2) orbit allows:**
  - High observing efficiency
  - Simultaneous viewing

- **Reference configuration:**
  - Four satellites, launched two at a time on Atlas V class vehicle
  - Extendible or fixed optical bench provides a focal length of 10 m
  - Modular design allows:
    - > Parallel development and integration of instrument module and spacecraft bus
    - > Low cost standard bus architecture and components

Reference Design



Launch Configuration

Spacecraft Module

Instrument Module

High Gain Antenna
(hidden from view)

Hard X-ray Telescope
Mirrors (3)

1.6 m Spectroscopy X-ray
Telescope Mirror/Gratings

Hard X-ray Detectors

CCD Array

Cryostat and
X-ray Calorimeter

Spacecraft Bus Component
Compartments

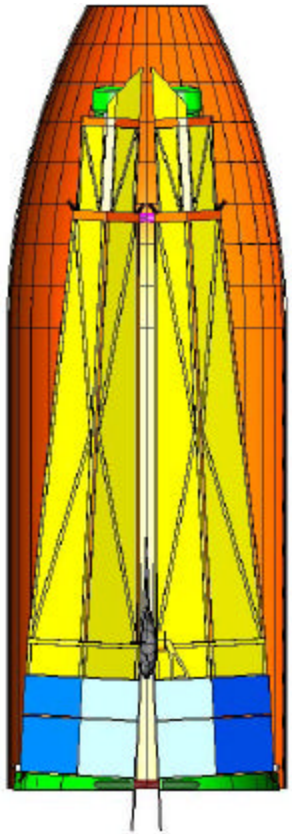
Solar Panel

Extendible Optical Bench
(light tight enclosure removed for clarity)

Instrument Electronics

Sunshade

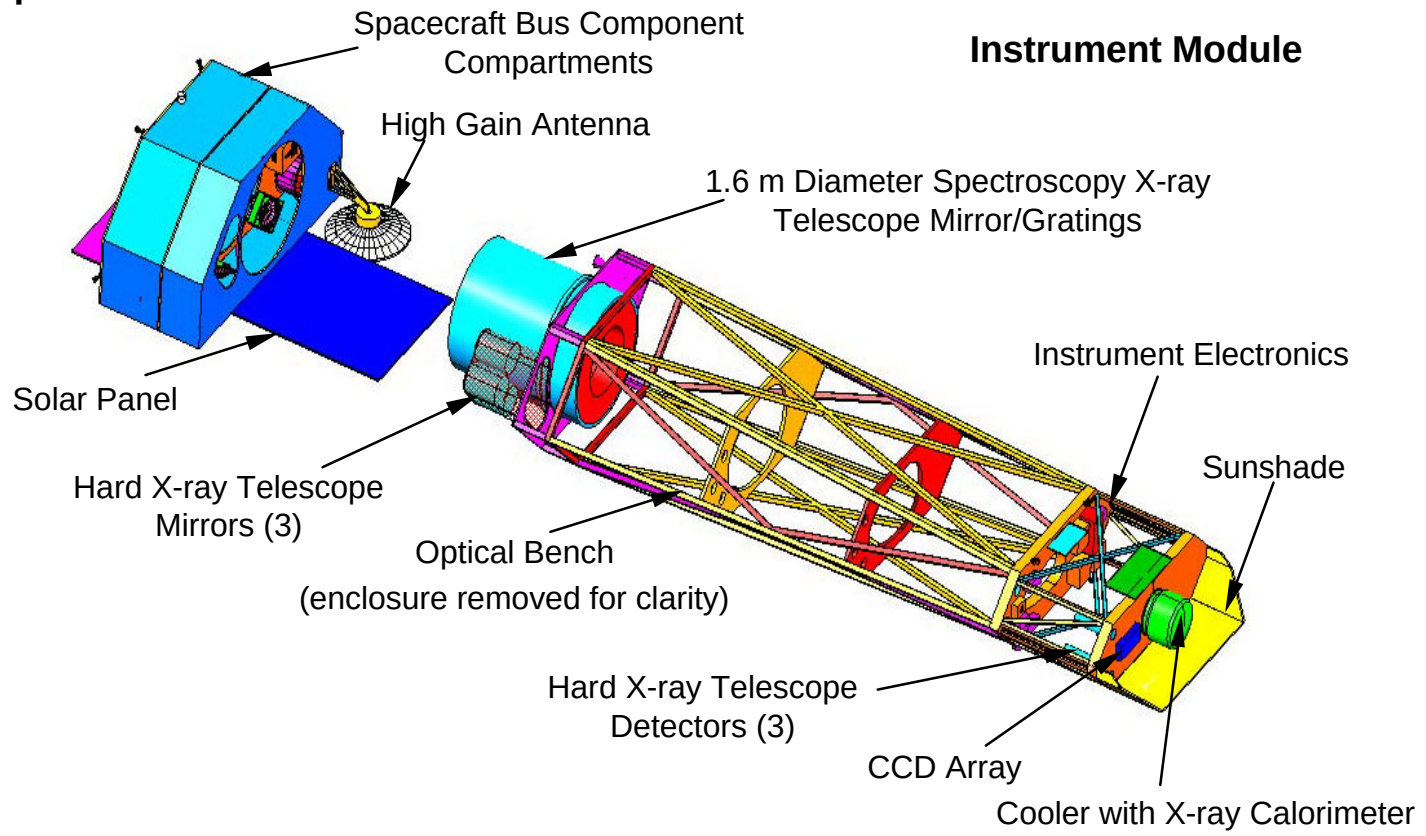
Fixed Bench Option



Launch Configuration

Spacecraft Module

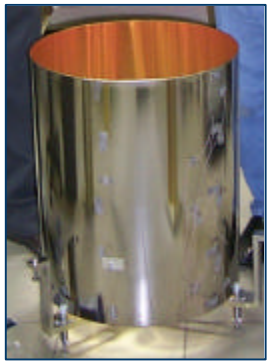
Instrument Module

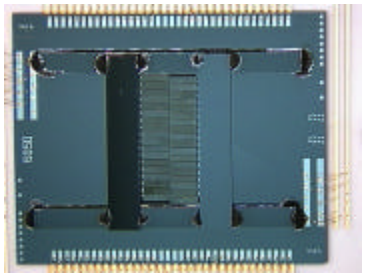


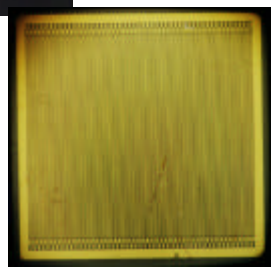
Constellation-X Requirements Flow Down

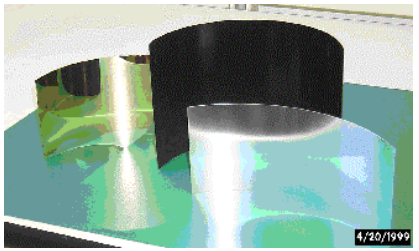
Science Goals	Measurement Capabilities	Engineering Implications	Key Technologies
Parameters of Supermassive Black Holes **Search for Dark Matter** **Investigate Faint Sources** **Plasma Diagnostics from Stars to Clusters**	**Effective area:** 15,000 cm² at 1 keV 6,000 cm² at 6.4 keV 1,500 cm² at 40 keV **Band pass:** 0.25 to 40 keV **Spectral resolving power (E/ΔE):** ≥ 300 from 0.25 to 6.0 keV ≥ 3000 at 6 keV ≥ 10 at 40 keV **System angular resolution and FOV:** 15 arc sec HPD and FOV > 2.5' (0.25 to 10 keV) 1 arc min HPD and FOV > 8' (10 to 40 keV)	**Effective area:** • Light weight, highly nested, large diameter (1.6 m) optics • Long focal length (8-10 m) **Band pass:** • 2 types of telescopes to cover energy range **Spectral resolving power:** • Dispersive *and* non-dispersive capability to cover energy band **System angular resolution and FOV:** • Tight tolerances on telescope figure, surface finish, alignment • ≥ 30 x 30 array for x-ray calorimeter (pixels ~5") • Cryocooler driven by array size and readout electronics	**High throughput optics:** • High performance replicated shells and segments • High reflectance coatings • High strength/mass materials for optical surfaces **High energy band:** • Multilayer optics • CdZnTe detectors **High spectral resolution:** • 2 eV calorimeter arrays • Coolers • Lightweight gratings • CCD arrays extending to 0.25 keV **Optical bench:** • Stable (time and temp.) • High strength/low weight materials

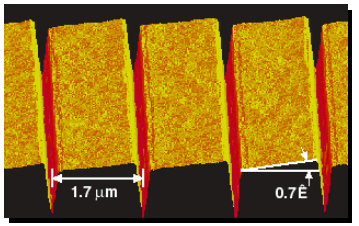
Technology Development Approach







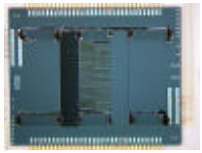




- **Extension of demonstrated technology**
- **Parallel path technology development with defined selection milestones**
- **Leverages other technology investments:**
  - Cross-enterprise (coolers, optics, X-ray calorimeter)
  - SR&T (CdZnTe and calorimeter detectors, multi-layer coatings)
  - NASA Center IR&D and DDF (optics, coolers)
  - SBIR (optics)

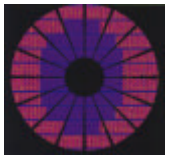
The Constellation-X Technology Roadmap

X-ray Mirrors



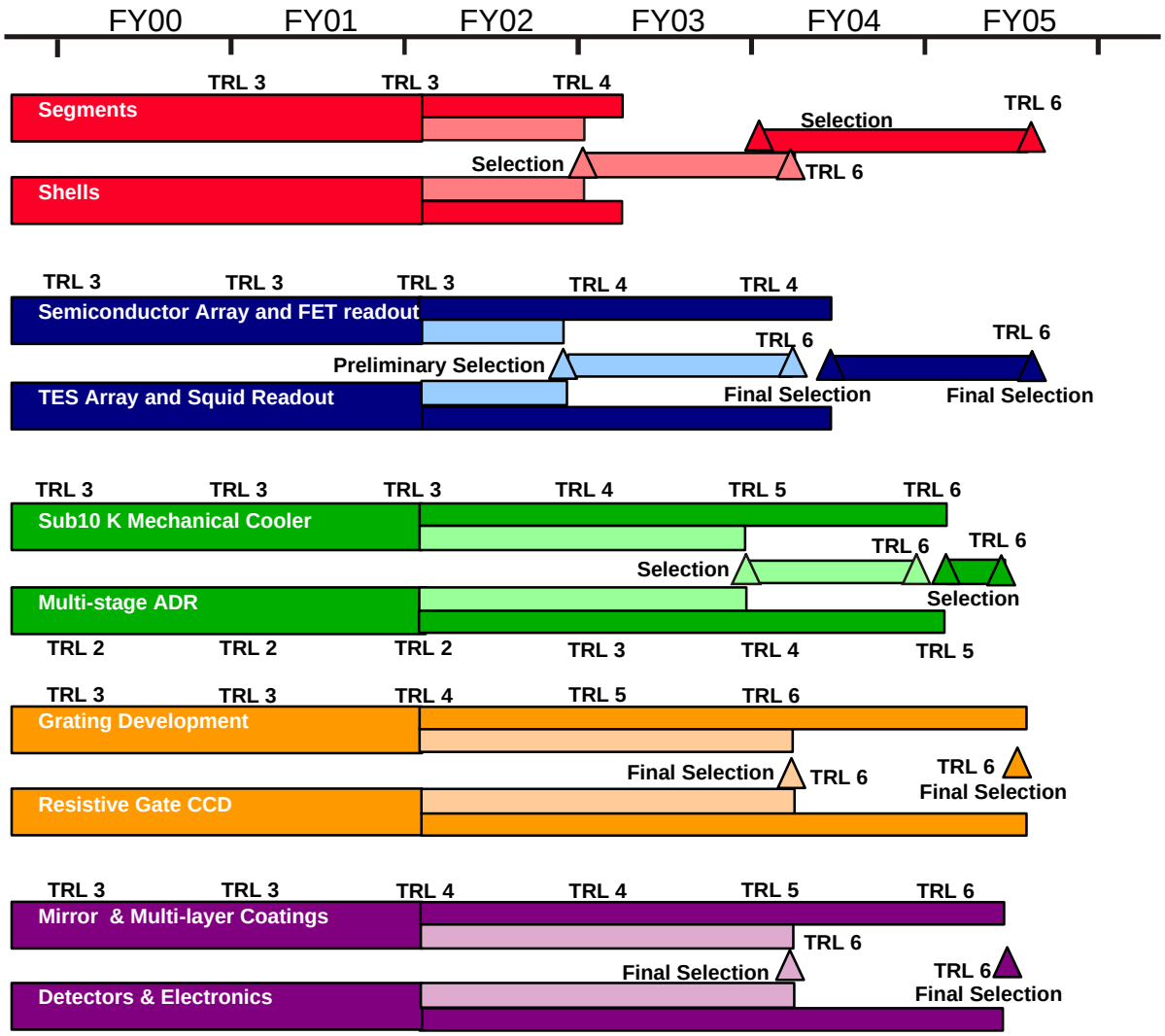
X-ray Calorimeters

Cryocoolers



Grating/CCD

Hard X-ray Telescope



Solid Colored ▲ Technology development plan for current in-guide budget; meets FY2007 New Start

Shaded Light ▲ Plan requires augmentation to meet 2005 new start

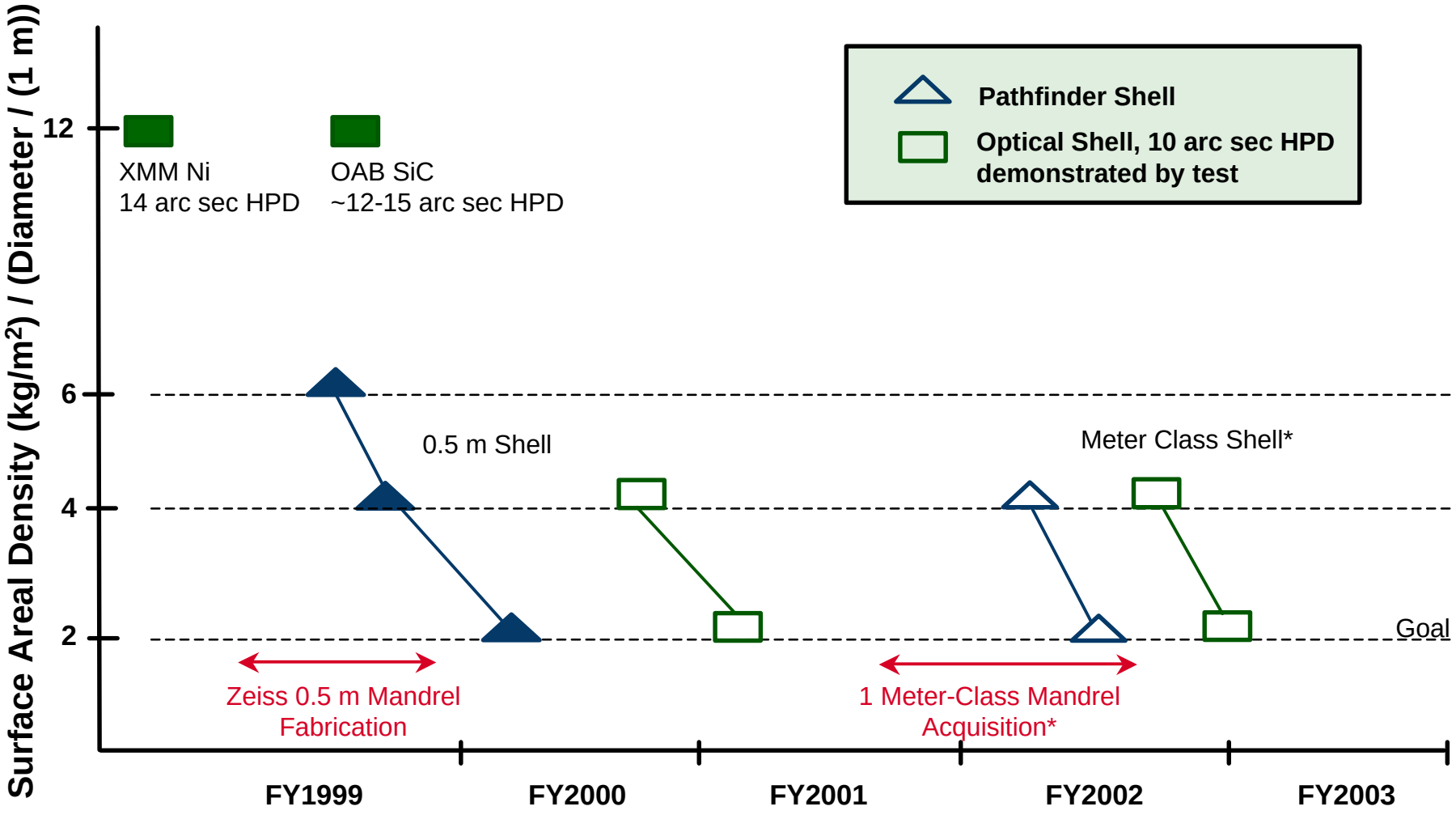
SXT Replicated Shell X-ray Mirrors

- **Requirement: Highly nested replicated shells with 1.6 m outer diameter, surface areal density ranging from 1 kg/m^2 to 3.2 kg/m^2, and angular resolution $\leq$ 10 arc sec (HPD)**
  - Requires **6X** lower scaled mass; **2.3X** greater diameter compared to XMM mirror
- **Progress:**
  - Received two 0.5 m mandrels from Zeiss (HPD < 5 arc sec)
  - Refined high micro-yield nickel alloy electroplating bath
    - > Reduced plating stress sensitivity and nonuniformity
  - Demonstrated robust mandrel overcoat to control surface adhesion
  - Fabricated 0.5 m shell meeting flight mass requirement (1 kg)
  - Completed construction of Large Space Optics Plating Facility at MSFC
  - Established ongoing dialog with Zeiss (Germany) and Raytheon Optical Systems, Inc. (Danbury)

1-kg 0.5 m Shell

- **Plans:**
  - Conclude optimization of nickel electroforming chemistry; develop plate stiffened structures
  - Begin preparations for meter class optic replication; fabricate meter class pathfinder mandrel
  - Evaluate non-integral carrier replication with pathfinder mandrel (.25 m)
  - Begin flight mirror development planning
- **Partners: MSFC, SAO, OAB**

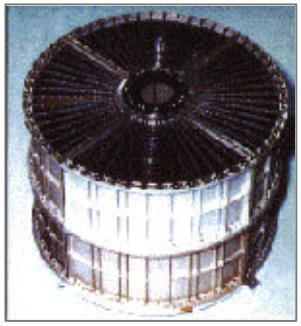
SXT Replicated Shell X-ray Mirror Metrics



* Meter class shell schedule limited by funding for meter class mandrel.
Could be accelerated by additional FY00 or FY01 funds.

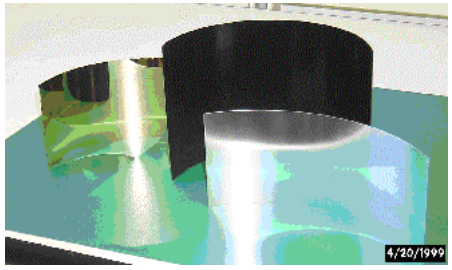
SXT Segmented X-ray Mirrors

- **Requirement: Highly nested replicated shells with 1.6 m outer diameter, surface areal density ranging from 1 kg/m^2 to 3.2 kg/m^2, and angular resolution ≤ 10 arc sec (HPD)**
  - Segmented technology meets mass requirement
  - Requires **10X** improvement in resolution and **4X** increase in diameter compared to Astro-E



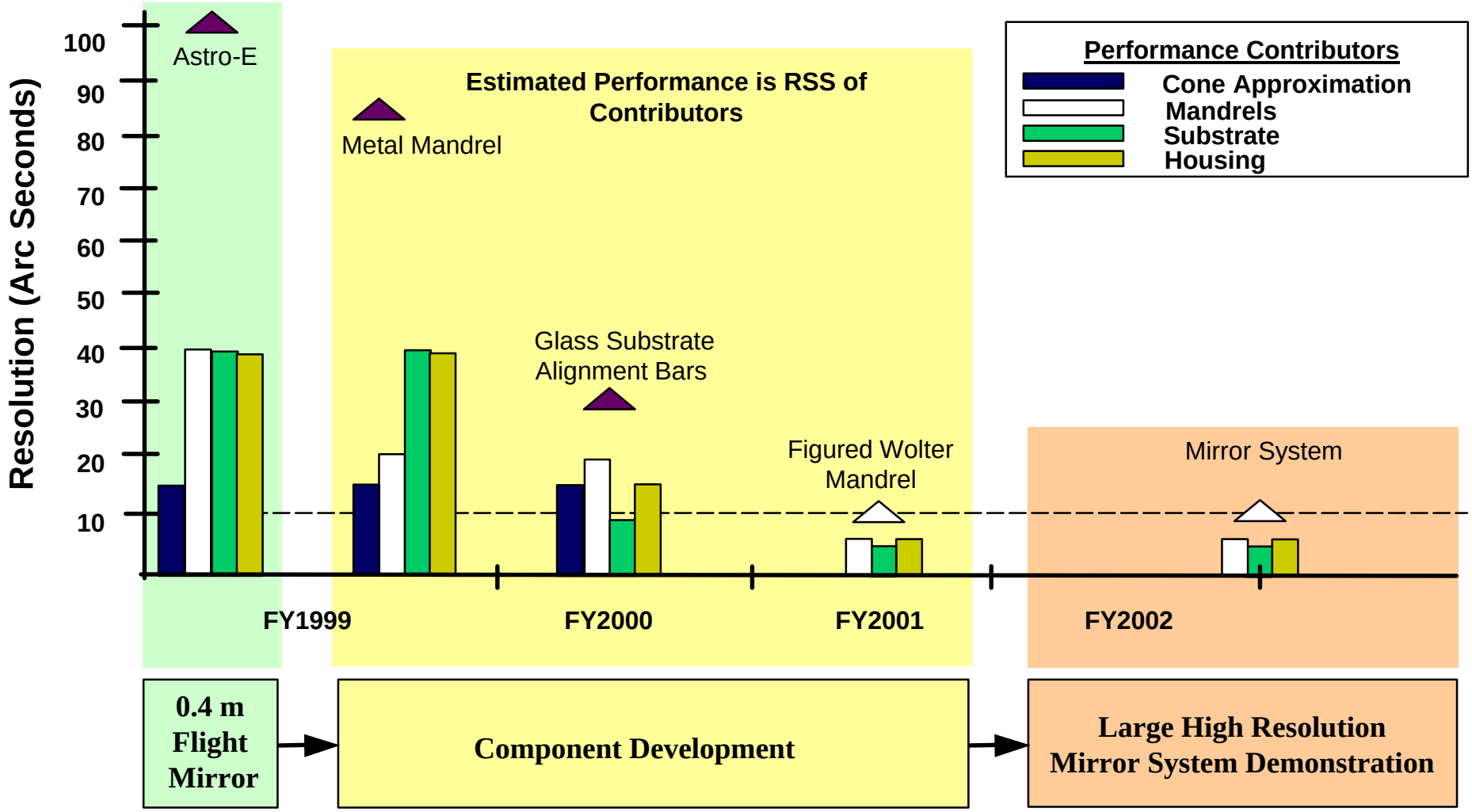
- **Progress:**
  - Demonstrated components consistent with 30 arc sec system HPD
    - > Glass substrate figure 10 arc sec (factor of 4 improvement)
    - > Positioning repeatability < 1 arc sec with silicon etched alignment bars (factor of 60 improvement)
    - > Conical metal mandrel figure 15 arc sec (factor of 3 improvement)
  - Produced 0.5 m Be substrate suitable for replicating
  - Established ongoing dialog with Zeiss and Raytheon Optical Systems, Inc.

- **Plans:**
  - Replicate axially curved surfaces (Wolter geometry)
  - Replicate larger (0.5 m) substrates
  - Demonstrate resolution for conical glass reflector pair
  - Demonstrate performance of alignment bars in prototype fixture
  - Begin flight mirror development planning

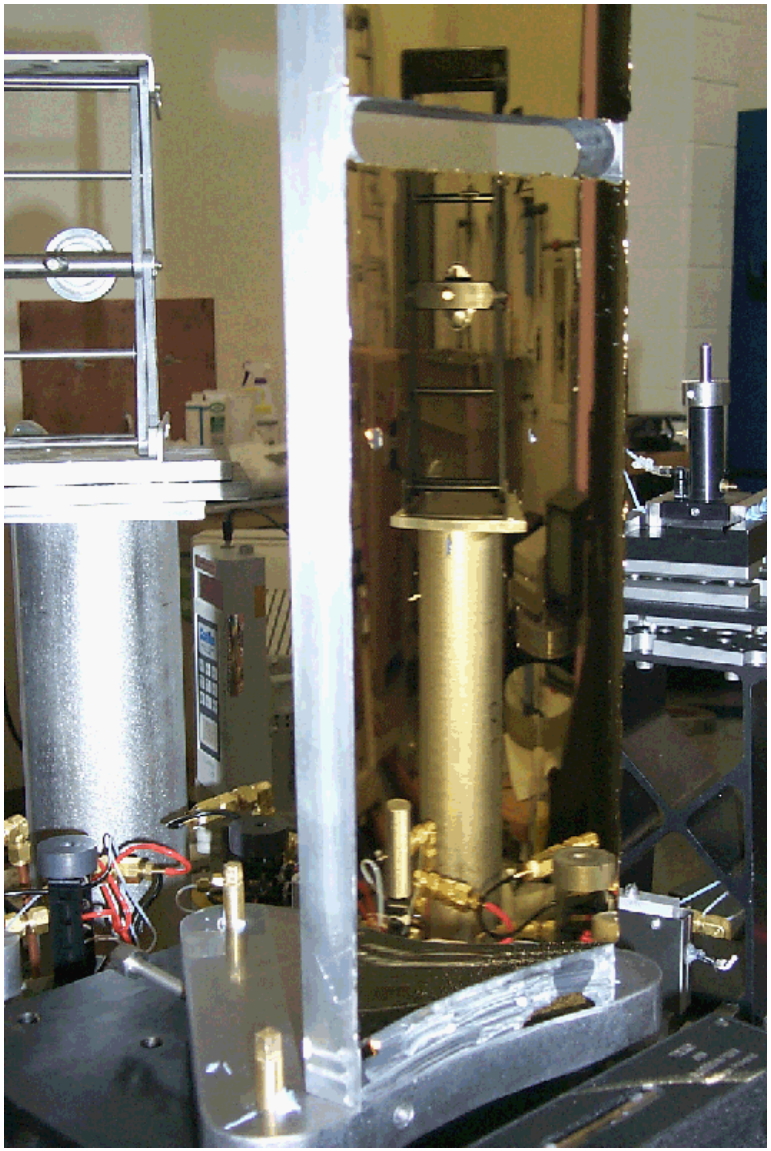


- **Partners: GSFC, MIT, SAO, RJHS**

SXT Segmented X-ray Mirror Metrics

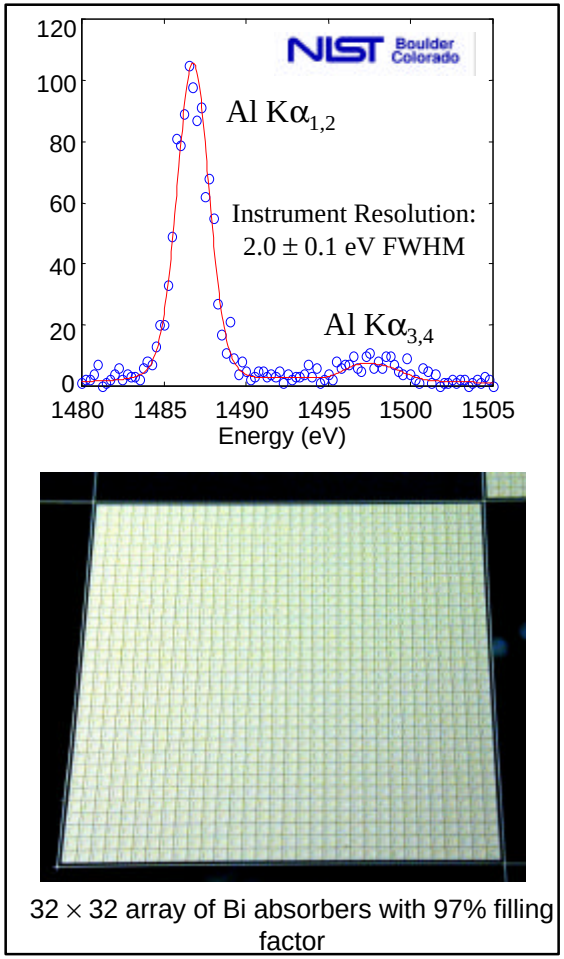


Replicated 0.5 m Segment



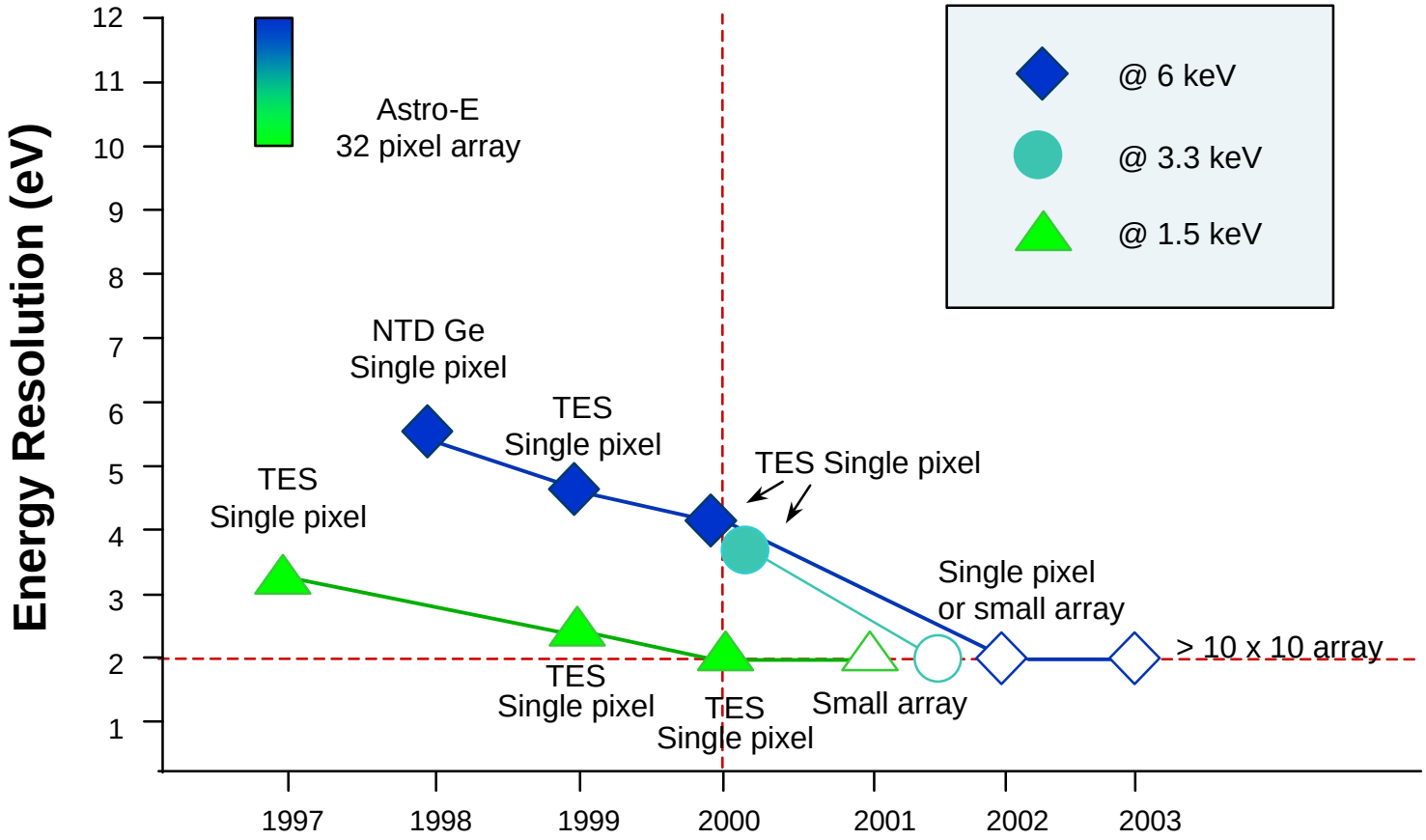
X-ray Calorimeters

- **Requirement: 2 eV FWHM energy resolution from 1 to 6 keV at 1000 counts/s/pixel in 32 x 32 pixel array**
- **Parallel Approach: Transition Edge Sensor (TES) and NTD/Ge Calorimeters**
- **Progress:**
  - Achieved 2.0 eV at 1.5 keV for Al/Ag TES with Bi absorber
  - Achieved 3.7 eV at 3.3 keV for fully microfabricated Mo/Au TES without absorber
  - Achieved 4.5 eV at 6.0 keV for fully microfabricated Mo/Cu TES without absorber
  - Demonstrated absorber scheme for fully monolithic 32 × 32 arrays of TES calorimeters
  - Completed design of photolithographic mask set for testing components critical for large TES arrays
- **Plans:**
  - Continue to fabricate single pixel detectors with a range of parameters for higher resolution performance
  - Establish integrated TES array processing
  - Fabricate small, functional TES arrays (e.g., 3 × 3)
- **Partners: GSFC, NIST, SAO, UW, LLNL, Stanford**



32 × 32 array of Bi absorbers with 97% filling factor

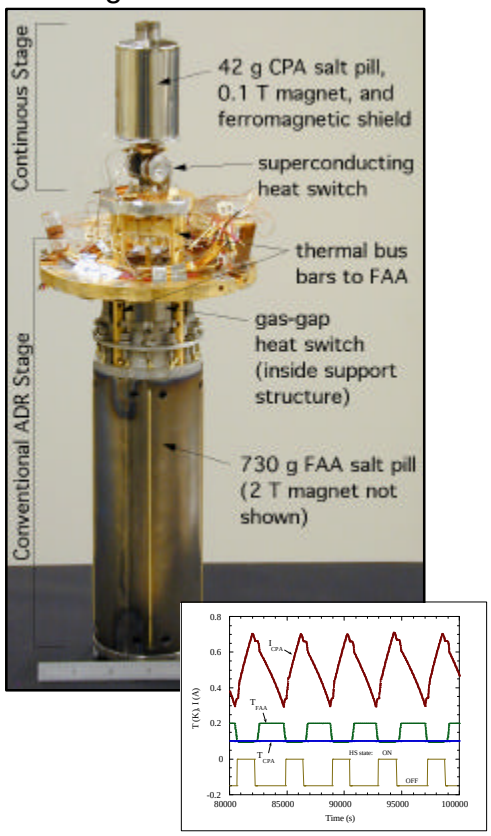
X-ray Calorimeter Metrics



Cooling System for X-ray Calorimeter

- **Requirement: Long life cooling system that provide 40 to 65 milli Kelvin at X-ray calorimeter**
- **Approach: Sub10-Kelvin mechanical cooler to provide heat sink to sub-Kelvin Adiabatic Demagnetization Refrigerator (ADR)**
- **ADR Progress:**
  - Successfully demonstrated continuous cooling at 100 milli Kelvin
  - Began development of a 1 to 10 Kelvin stage and a liquid gap heat switch
  - Submitted Cross Enterprise proposal for ADR component and system development
- **Mechanical Cooler Progress:**
  - 70 K turbo Brayton cooler in acceptance test for next HST servicing mission
  - Acquisition of 6-8 K cryo cooler technology is underway and SOW reflects the requirement of NGST/TPF/Constellation-X

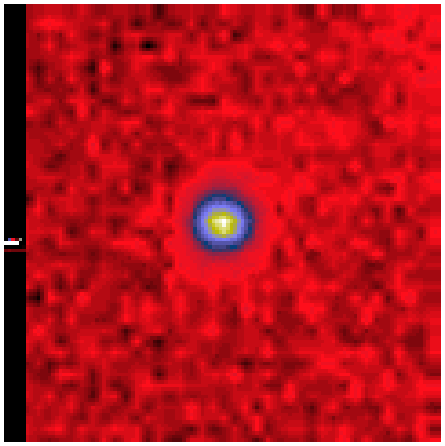
2-Stage Continuous ADR



- **Partnership: GSFC, JPL, Creare, Energen, Houston U., Berkley**

Hard X-ray Telescope

- **Requirement: Maximum energy ≥ 40 keV, effective area ≥ 1500 cm², angular resolution ≤ 1 arc min HPD, FOV 8 arc min, energy resolution ≤ 10%**
- **Approach: Depth-graded multilayer grazing incidence optics and CdZnTe pixel detectors**
- **Progress:**
  - Improved CdZnTe detector performance
    - > Energy resolution 390 eV (at 18 keV) and 550 eV (at 60 keV)
    - > Threshold below 2 keV
  - Fabricated high-reflectance (4A interface width) depth-graded multilayers
  - Demonstrated sputter coating on interior of cylindrical shells
  - Evaluated formed glass prototype optic with 5 coated surfaces
    - > 35 arc sec HPD and good reflectance at 60 keV (single bounce)

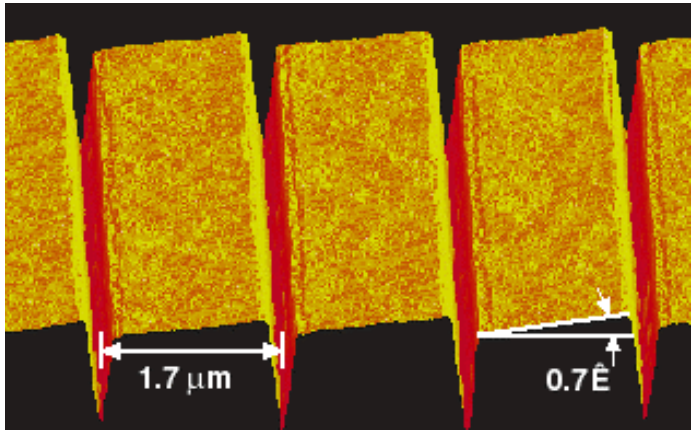


68 keV image
glass prototype

- **Plans:**
  - Complete cross evaluation of W/Si, Pt/C and Ni/C coatings
  - Measure low energy efficiency of CdZnTe detectors
  - Hard X-ray balloon flights planned for 2001 to 2002
- **Partners: Caltech, GSFC, Columbia U., MSFC, Harvard, SAO, NU, NRL**

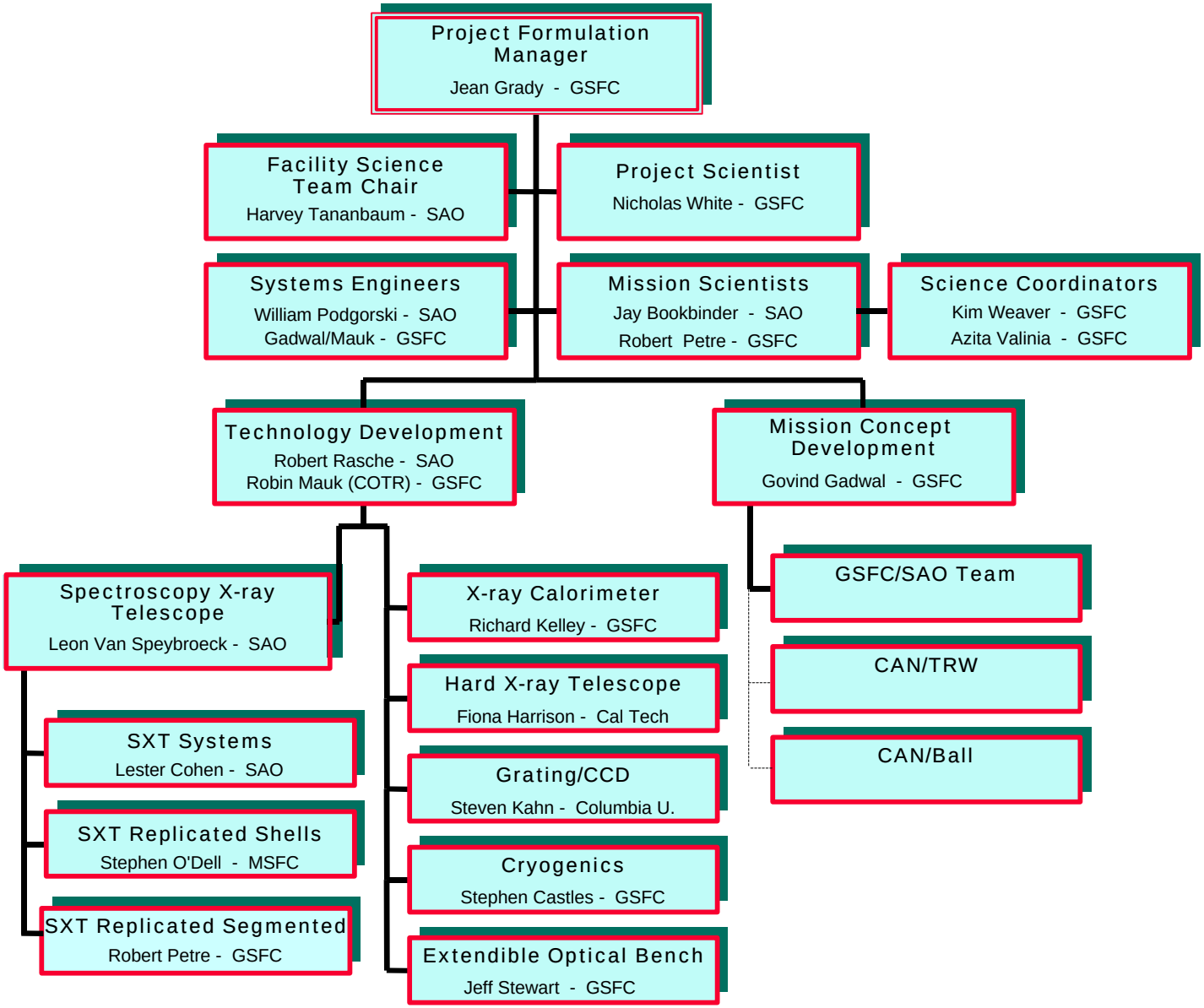
Reflection Gratings / CCD

- **Requirement: High throughput, high resolution reflection grating spectrometer for 0.25 keV to 2.0 keV, with low mass and producible from high yield processes**
- **Approach: Anisotropic Interference lithography on silicon wafers; and resistive gate CCDs**
- **Progress:**
  - Measured efficiency ~23% for prototype grating at 1.5 keV
  - Demonstrated process for reducing large-scale warping of grating substrate
  - First lot of Resistive Gate CCDs demonstrate concept; two operating packages respond at 6 keV
- **Plans:**
  - Demonstrate technique for achieving small scale flatness (0.1 micron) over entire grating substrate
  - Develop fabrication plan for second lot RGCCD; address resistance uniformity for charge transfer
- **Partners: Columbia U., MIT, Penn State**

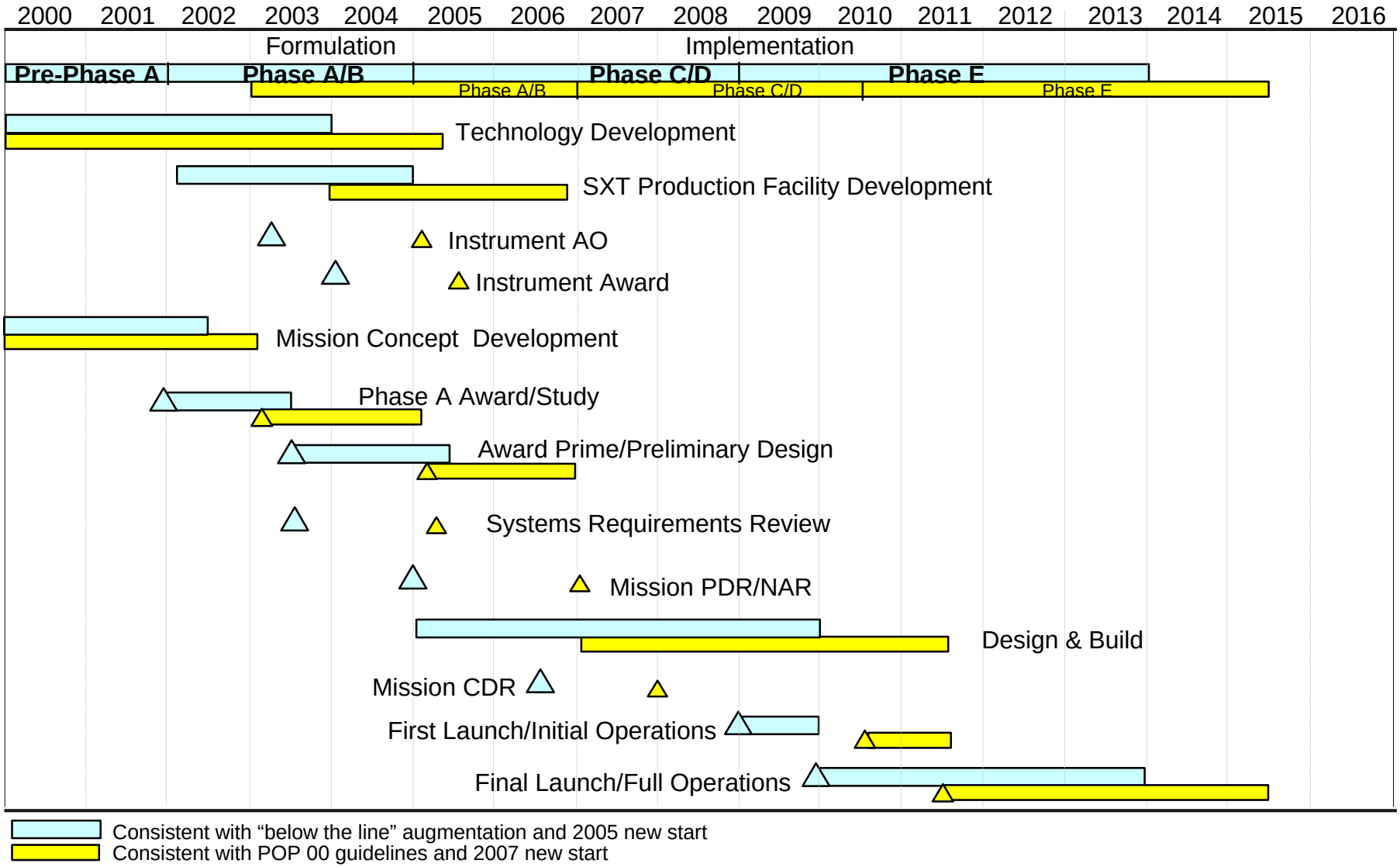


Fabricated with anisotropic etches on silicon

Organization



Top Level Schedule



The Outlook for Constellation-X

- **One-year outlook (Spring 2001)**
  - Demonstrate performance requirement with flight weight 0.5 meter optics
  - Top level mission requirements and requirements flow down released
- **Five-year Outlook (Spring 2005)**
  - With current in-guide budget:
    - > Technology Development complete
    - > Instrument AO released, instruments selected and under contract
    - > Phase A study complete
    - > Systems Requirement Review complete and preliminary design underway
  - With “Below the Line” budget:
    - > Mission NAR and PDR complete
    - > Detail design underway

Summary

- **Chandra observations are demonstrating anticipated richness of X-ray spectra**
- **Constellation-X emphasizes high throughput, high spectral resolution observations – the next major objective in X-ray astronomy**
- **Substantial technical progress achieved with limited funding**
  - 2 eV spectral resolution at 1.5 keV with calorimeter
  - Shell optic factor of 6 lower mass than with XMM technology
  - Performance required for hard X-ray telescope optics and detectors demonstrated
- **Mission concept is low-risk and robust**
- **Mission can be ready for a 2005 new start; 2008 – 2009 launches**
  - Requires significant funding augmentation beginning in 2002
  - Provides for timely transition and continuity in high quality X-ray observations